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Morpho-biochemical Evaluation of Three Sugar Apple (*Annona squamosa* L.) Genotypes

Md. Mahfuzul Hasan, Md. Mokter Hossain*, Tamanna Haque, Amit Kumar Basunia, Nayan Chandra Howlader

Department of Horticulture, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

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ABSTRACT

Sugar apple is an underutilized minor and non-traditional nutritious fruit in the southern regions of Bangladesh. The target of this study was to evaluate the morphological, biochemical, and mineral traits of sugar apple genotypes for selecting superior genotypes. Three sugar apple genotypes were used for this study and it was conducted following a randomized complete block design with three replicates. Results indicated that significant differences existed among the sugar apple genotypes. The highest fruit length (9.25 cm), fruit width (9.63 cm), fresh fruit weight (149 g), ripe fruit weight (137.80 g), pulp weight (91.00 g), peel weight (32.25 g), edible portion (66.08%), the number of seeds per fruit (50.25), seed length (12.94 mm), seed width (8.69 mm), seed fresh weight (14.50 g fruit^{-1}), seeded pulp (76.59%), dry matter content (30.01%), pH (5.50), ascorbic acid (36.28 mg 100g^{-1}), P (117.63 mg 100 g^{-1} DW), S (542.09 mg 100 g^{-1} DW), and Fe (6.21 mg 100 g^{-1} DW) were obtained in the G_3 genotype compared to other genotypes. On the other hand, G_1 showed the highest amount of fruit peel (29.94%), moisture content (73.54%), and non-reducing sugar (5.36%). Genotype G_2 showed maximum values regarding total soluble solids (25.50%), total sugar (20.06%), reducing sugar (15.36%), Ca (359.60 mg 100 g^{-1} DW), and Mg (326.95 mg 100 g^{-1} DW) contents. It can be summarized that genotype G_3 exhibited superior performance in morphological and biochemical properties of fruits and the majority of mineral contents.

Introduction

Sugar apples (*Annona squamosa* L.) are attractive, deciduous, slow-growing shrubs or small trees in the Annonaceae family. The genus *Annona* derives from the Latin word '*anon*,' which means 'yearly produce,' concerning 'the fruit production habits of the various species within this genus' (Orwa et al., 2009). In the Indian subcontinent, sugar apples are known by numerous names, including sitaphal, sweet sop, misti ata, sharifa, and mewa. In South Asia, *Annona squamosa* is sometimes called custard apple even though it indicates *Annona reticulata*. It is a diploid species (2n=14 and 16), extensively cultivated in Central America, Thailand, Malaysia, the Philippines, Vietnam, and some parts of India. In Bangladesh, it is mainly cultivated in the homestead area. It is

*Corresponding author's email: mokter.agr@bau.edu.bd

considered an underutilized minor fruit in Bangladesh. There is a high market demand for sugar apple fruits due to their nutritional benefits for human health. Currently, sugar apples appear commercially in many areas of the country. The total area under sugar apple cultivation is 717.42 ha. with a production of 5149.13 metric tons (BBS, 2022). The area under cultivation of this fruit is increasing rapidly, but there is no such a recommended high-yielding variety of sugar apple. Farmers are growing local cultivars or genotypes in the orchards and homesteads. It is a crop of high nutritional value because it contains almost all essential minerals such as potassium, calcium, magnesium, phosphorus, sulfur, iron), vitamin C, and carbohydrates.

Sugar apples are full of vitamins and minerals. It contains antioxidants called carotenoids. Antioxidants fight with free radicals in the body and keep the human body free from several chronic diseases. It is a good source of fiber, which is crucial for healthy digestion. Sugar apple leaf contain phenols, flavonoids, and other bioactive compounds that may have anti-cancer, antimicrobial antidiabetic, and anti-inflammatory properties. Sugar apple seeds are also a vital source of prebiotics.

Sugar apples are naturally resilient and cross-pollinated. Large inter and intra-specific variations occur among the quality traits of sugar apples. As a result, it exhibits substantial variation in form, color, size, quality, and fruiting propensity (Bharad et al., 2009; Kad et al., 2016). Variations can also be seen in the color of skin and flesh. Generally, the outer skin color of sugar apples can be seen in distinct variations of green, greenish-yellow, and pinkish-red. The color of its inner pulp is mainly white and creamy. Inside the flesh, there are numerous, small, shiny, dark brown, brown, and black elongated or half oval or cylindrical-shaped seeds.

The market-standard quality and grade of these fruits are determined by their size, shape, fresh weight, and color. The greater market value is attributed to larger produce with a superior visible appearance of sugar apples (Souza et al., 2012).

According to Chitarra and Chitarra (2005), fruit quality comprises the attributes responsible for appearance, flavor, aroma, texture, nutritional composition, safety, size, weight, color, firmness, sweetness, acidity, and physical and physiologic defects. Due to wide variations in fruit color, shape, size, and nutritional quality of sugar apples, it is necessary to explore a superior genotype for future varietal development for high yield and nutritional quality of sugar apples. Therefore, this study aimed to find a superior sugar apple genotype for higher yield and nutritional quality for future varietal development.

Materials and Methods

Experimental site

A field experiment was conducted at the Bangladesh Agricultural University Germplasm Centre (BAU-GPC) from February to December 2022. Biochemical and nutrient-related studies were carried out at the postgraduate laboratory of the Department of Horticulture and the Laboratory of the Department of Agricultural Chemistry, BAU, Mymensingh. The soil in the experimental area had a silty loam texture and belonged to the Old Brahmaputra Flood Plain within Agro-ecological Zone 9, which was derived from Old Brahmaputra deposits with non-calcareous, dark grey floodplain soil (FAO, 1988). Sugar apple plants were grown in medium-high land with a soil of pH 6.8.

Planting materials and experimental design

Three sugar apple genotypes, namely, G_1, G_2, and G_3, were selected from the Bangladesh Agricultural University Germplasm Center (BAU-GPC) for this study. This single-factor study was conducted following a randomized complete block design with three replications. The age of the sugar apple trees was 7-8 years. A single plant was considered a replication.

Collection of data

Morphological traits of fruits such as fruit shape, length, breadth, skin, and flesh color were recorded after harvesting of mature fruit. Fruit length and breadth were measured by slide calipers and expressed as centimeters (cm). Fruit shape was classified as almost round or globose conic (heart-shaped) or conic and recorded by visual observation. Fruit skin and flesh color were determined by comparing with a color chart and recorded. The weight of fresh and ripened fruits was taken using digital balance and expressed in grams (g). Fruit peel was separated after ripening the fruits, and each segment was also weighed using a similar balance.

Seeded pulp (%)

The seeded pulp content of the fruit was calculated using the following formula (Kachhadiya and Jethva, 2017):

$$\text{Seeded pulp content (\%)} = \frac{\text{Seeded pulp weight (g)}}{\text{Weight of fruit (g)}} \times 100$$

Peel content (%)

Peel content of fruit was calculated using the following formula (Kachhadiya and Jethva, 2017):

$$\text{Peel content (\%)} = \frac{\text{Peel weight (g)}}{\text{Weight of fruit (g)}} \times 100$$

Edible portion (%)

Initially, the entire weight of stemless produce was determined using a balance. Then, using a pointed knife, the fruit was skinned, the receptacle and seeds were removed, and the residual pulp was weighed. The percentage of fruit that is edible was calculated using the following equation (Ranganna, 1994).

$$\text{Edible portion (EP) (\%)} = \frac{\text{Weight of edible portion (g)}}{\text{Total weight of fruit (g)}} \times 100$$

Number of seeds per fruit

Total number of seeds per fruit were counted and recorded. Pulp weight and total number of seeds per fruit weight were calculated in proportion.

Biochemical traits

Sample preparation

Mature sugar apple fruits were harvested from the plants and transferred to the Postgraduate Laboratory of the Department of Horticulture for morphological and nutritional analysis. Fruits were kept in storage for a couple of days for ripening. Thereafter, unblemished and ripened fruits were rinsed with distilled water, and the surface water of each sugar apple was blotted away with aseptic tissue paper. The samples of sanitized, air-dried sugar apple fruits were removed and skinned with a sharp knife.

Determination of moisture and dry matter contents (%)

Twenty g of fruit flesh were wrapped in aluminum foil and kept in an electric oven for drying at 75 °C until the weight remained constant. Thereafter, dry weight was measured, and the percentage of hydration in each sugar apple was calculated using the following formula:

$$\text{Per cent moisture content} = \frac{\text{Initial weight (g)} - \text{Final weight (g)}}{\text{Initial weight (g)}} \times 100$$

The following equation was then used to calculate the dry matter content:

$$\text{Per cent dry matter} = \frac{\text{Dry weight (g)}}{\text{Fresh weight (g)}} \times 100$$

Determination of pH

A pH meter with a glass electrode (Senso Direct pH 110, United Kingdom) was used to measure the pH of a fruit sample. In brief, 5 g of fruit from each sample was placed in a 50-mL beaker and 25 mL of distilled water was added. The suspension was vigorously agitated for ten minutes and allowed to rest for two minutes. The electrode of the pH meter was immersed in the solution, and the pH reading was recorded.

Determination of titratable acidity (%)

The concentration of titratable acid was determined following a method described by Ranganna (1979). In brief, fruit flesh was homogenized with distilled water in a mixer, boiled for 60 min under reflux, transferred to a 100 mL volumetric flask, and the volume was brought up to the mark with distilled water, the required extract was taken, two to three drops of phenolphthalein indicator were added, and the mixture was vigorously stirred before titration with 0.1 N NaOH solution. The required NaOH solution volume for titration was noted, and the titratable acidity percentage was calculated using the following formula.

$$\text{Titratable acidity (\%)} = \frac{\text{Titre} \times \text{Normality of NaOH} \times \text{Volume made up (mL)} \times \text{Equivalent weight}}{\text{Volume of extract (mL)} \times \text{Weight of sample (g)} \times 1000} \times 100$$

Determination of ascorbic acid (mg 100g^{-1})

The quantity of ascorbic acid was determined using the method of 2, 6-dichlorophenol-indophenol (DCPIP) visual titration (AOAC, 1984). The required quantity of fresh fruits and 70 mL of a 6% solution of metaphosphoric acid were blended for two minutes, filtered, and centrifuged at 2000 rpm for five minutes. This was followed by transferring the homogenized supernatant to a volumetric vial of 100 mL and adjusting the volume with 6% metaphosphoric acid. The aliquot was transferred to a conical flask and titrated using a dye solution.

Using the following formula, the ascorbic acid concentration in each sample was calculated.

$$\text{Ascorbic acid content } (mg\ 100\text{g}^{-1}) = \frac{\text{Titre} \times \text{Dye factor} \times \text{Volume made up (mL)}}{\text{Volume of the extract (mL)} \times \text{Weightof sample (g)}} \times 100$$

Determination of total soluble solids (°Brix)

Using an Abbe's Hand refractometer (Atago Co. Ltd., Japan), the TSS content of apple purée was determined. A method described by Ranganna (1979) was used for making temperature corrections.

Determination of total sugar (%)

The total sugar content of sugar apple flesh was determined calorimetrically, following the Anthrone Method (Jayaraman, 1981). Fruit flesh was segmented, immersed for five to ten min in scalding ethyl alcohol, filtered, re-extracted for three min in hot 80% alcohols, refrigerated, and filtered through filter paper. Both extracts were filtered by using a Whatman No. 1 filter paper. Approximately a quarter of the extract volume was evaporated using a thermal steam chamber and then chilled. Absorbance was measured at 620 nm using a colorimeter (LT-114, India). The total sugar content in each extract was calculated. The following formula was used for determining the quantity (percentage) of total sugar:

$$\text{Per cent total sugar} = \frac{\text{Amount of total sugar obtained}}{\text{Weight of sample}} \times 100$$

Determination of reducing and non-reducing sugars (%)

The reducing sugar content of sugar apple flesh was determined using the dinitrosalicylic acid method developed by Miller (1972). Fruit flesh was cut into small segments, immersed for 5 to 10 min in scalding ethyl alcohol, filtered, re-extracted for 3 min in hot 80% alcohol, refrigerated, and filtered through filter paper. Each isolate was filtered with filter paper. Approximately 25% of the extract volume was evaporated before immersion in boiling water for cooling. The absorbance of the solution was determined using a colorimeter (LT-114, India) at 575 nm. The quantity of reducing sugar in the extract was estimated by using the glucose standard curve.

Reducing sugar present in the sugar apple was determined using the following formula:

$$\text{Reducing sugar (\%)} = \frac{\text{Amount of reducing sugar obtained}}{\text{Weight of sample}} \times 100$$

Non-reducing sugar content of the sugar apples was calculated using the following formula:

$$\%\ \text{Non reducing sugar} = \%\ \text{Total sugar} - \%\ \text{reducing sugar}$$

Determination of mineral contents

In brief, 0.5 g of oven-dried fruit sample was subjected to moist digestion with HNO_3 and $HCLO_4$ in an electrically heated plate at 180 to 200 °C until solid particles vanished and white vapors were produced. For analysis, the metabolized sample was drawn into the spectrophotometer.

Ca and Mg concentrations of sugar apple were determined by complexometric titration with EDTA as the complexing agent (AOAC, 1990). Phosphorus (P) content was determined using a spectrophotometer at 660 nm wavelengths (Model- T60, PG Instruments, UK). The sulfur (S) content of sugar apple fruit samples was determined by using the turbidimetric method (Chesnin and Yien, 1950). The amount of Fe contents of the sugar apple fruit sample was determined using atomic absorption spectrophotometry (AAS) (Model- AA-7000S, Shimadzu, Japan).

Statistical analysis

The collected data on various parameters were statistically analyzed with the Statistix 10 software program to determine variations caused by experimental treatments, i.e., sugar apple genotypes. The significance of the difference between the two means was compared by Duncan's Multiple Range Test (DMRT) at the 1% and 5% levels of probability (Gomez and Gomez, 1984).

Results

Morphological traits of fruits

The fruit shape, skin, and flesh color of the three sugar apple genotypes were different (Fig. 1). The fruit shape of sugar apple genotypes G_1, G_2, and G_3 was almost round, globose, and globose conic (heart-shaped), respectively (Fig. 1 and Table 1). Fruit skin and flesh color were also different among the three genotypes (Fig. 1). The skin color of sugar apple genotypes G_1, G_2, and G_3 was green, yellowish-green, and pinkish-red, respectively. The flesh color of G_1, G_2, and G_3 was white, brownish white, and creamy white, respectively (Fig. 1 and Table 1). Fruit length and width of sugar apple were significantly different among the genotypes. The longest fruit length (9.25 cm) and width (9.63 cm) appeared in G_3 and the shortest fruit length (7.52 cm) and width (6.80 cm) in G_2 (Table 1).

Weight of fresh fruit, ripen fruit, fruit pulp

There were significant variations in the fresh weight, ripe fruit weight and fruit pulp of the three sugar apple genotypes (Table 2). The highest values were obtained from the genotype G_3 (149.00 g, 137.80 g and 91.00 g, respectively) followed by G_2 (122.00 g, 113.00 g and 72.75 g, respectively) and the lowest value found from G_1 (116.00 g, 105.50 g and 63.25 g, respectively) (Table 2).

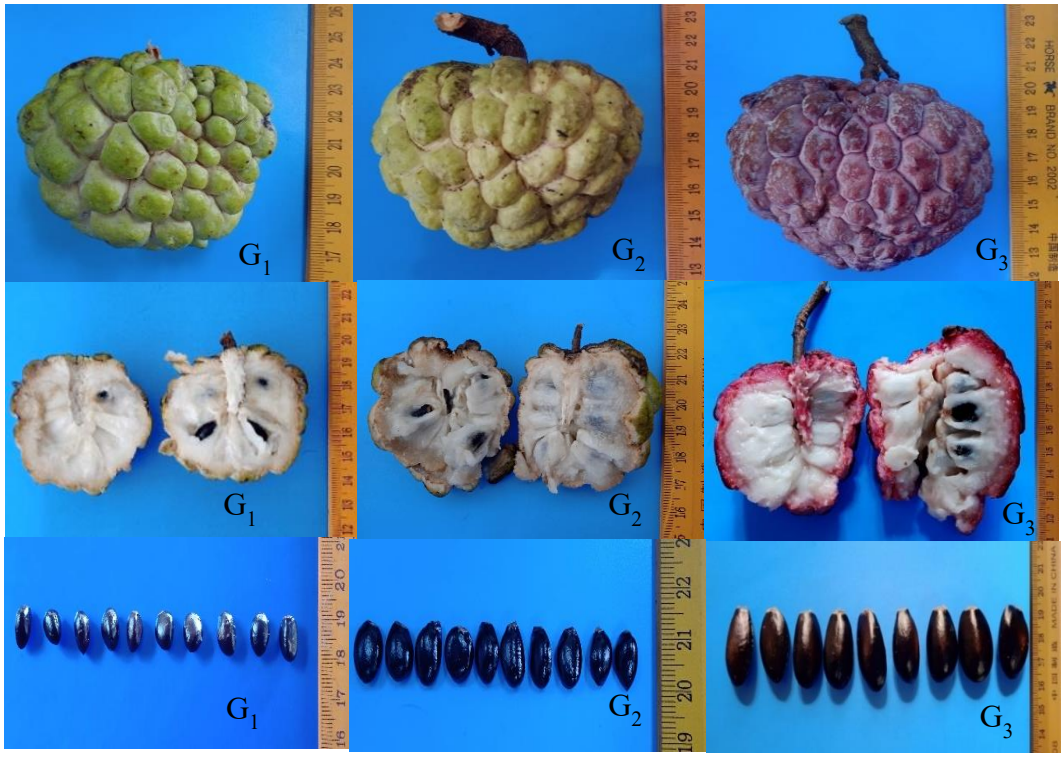

Fig. 1. Fruit shape, skin color, flesh color, fruit length and width of three sugar apple genotypes.

Table 1. Fruit shape, skin and flesh color, fruit length and width of three sugar apple genotypes.

Genotype	Fruit shape	Skin color	Flesh color	Fruit length (cm)	Fruit width (cm)
G_1	Almost round	Green	White	7.65[b]	7.03[b]
G_2	Globose	Yellowish green	Brownish white	7.52[b]	6.80[c]
G_3	Globose conic (Heart shaped)	Pinkish red	Creamy white	9.25[a]	9.63[a]
LSD 0.05				0.10	2.10
LSD 0.01				0.14	3.18
Level of signi.				**	**

Different letters in the column showing statistical significant difference at 1% probability.

Table 2. Fruit weight both fresh and ripen, fruit pulp, peel and edible portion of three sugar apple genotypes.

Genotypes	Weight of fresh fruit (g)	Weight of ripen fruit (g)	Weight of pulp (g fruit^{-1})	Seeded pulp content (%)	Weight of peel (g fruit^{-1})	Peel content (%)	Edible portion (%)
G_1	116.00[c]	105.25[c]	63.25[c]	70.74[b]	31.50[a]	29.94[a]	60.10[b]
G_2	122.00[b]	113.00[b]	72.75[b]	74.78[a]	27.75[b]	24.56[b]	64.39[a]
G_3	149.00[a]	137.80[a]	91.00[a]	76.59[a]	32.25[a]	23.41[b]	66.08[a]
LSD 0.05	2.10	4.08	4.21	2.32	2.78	2.74	2.38
LSD 0.01	3.18	6.13	6.38	3.52	4.21	4.16	3.60
Level of significance	**	**	**	**	**	**	**

Different letters in the column showing statistical significant difference at 1% probability.

Seeded pulp content, weight of fruit peel, peel content and edible portion

Statistical significant variations occurred regarding seeded pulp content, fruit peel weight, peel content and percentage of edible portions of the three sugar apple genotypes. The highest percentage of seeded pulp (76.59%) was obtained from G_3 which was statistically similar with G_2 (74.78%), and the lowest from G_1 (70.74%) (Table 2). The maximum fruit peel weight was recorded from G_3 (32.25 g) which was statistically identical to G_1 (31.50 g) and the minimum peel weight was obtained from G_2 (27.75 g). The lowest peel content (23.41%) with the highest edible portion (66.08%) were obtained from the genotype G_3 and these results were identical with G_2 (24.56% and 64.39%). The highest peel content (29.94% with the lowest edible portion (60.10%) was noticed in G1 (Table 2).

Seed traits of sugar apple genotypes

Statistical significant variations were observed on seed traits of the three sugar apple genotypes. It was found that G_3 produced the highest number of seeds per fruit (50.25), seed length (12.94 mm), seed width (8.69 mm) and seed weight (14.50 g) followed by G_2 (38.00, 10.54 mm, 6.34 mm, and 11.75 g, respectively) and the lowest value obtained from G_1 (35.00, 7.78 mm, 4.84 mm and 8.50 g) (Table 3).

Table 3. Effect of genotypes on no. of seeds per fruit, seed length (mm), seed width (mm) and fresh seed weight fruit^{-1} (g), moisture (%), dry matter (%) and pH.

Genotypes	No. of seeds fruit^{-1}	Seed length (mm)	Seed width (mm)	Seed weight (g fruit^{-1})	Moisture content (%)	Dry matter content (%)	pH
G_1	35.00^c	7.78^c	4.84^c	8.50^c	73.54^a	25.32^b	5.20^c
G_2	38.00^b	10.54^b	6.34^b	11 .75^b	72.05^b	26.48^b	5.40^b
G_3	50.25^a	12.94^a	8.69^a	14.50^a	70.06^c	30.01^a	5.50^a
LSD 0.05	0.20	1.30	0.07	0.97	0.08	1.18	0.02
LSD 0.01	0.76	1.96	0.10	1.45	0.12	1.80	0.08
Level of signi.	**	**	**	**	**	**	**

Different letters in the column showing statistical significant difference at 1% probability.

Biochemical properties of sugar apple

Biochemical properties of sugar apple such as moisture and dry matter contents, pH, titratable acidity, ascorbic acid, sugar contents, total soluble solids contents varied significantly among the genotypes. It was noticed that G_1 showed the maximum moisture content (73.54%), followed by G_2 (72.05%) and G_3 (70.06%) had the lowest moisture content (70.06%). Genotype G_3 contained the highest percentage of dry matter (30.01%), followed by G_2 (26.48%) and G_1 (25.32%) (Table 3). The highest pH was obtained in G_3 (5.50) followed by G_2 (5.40), and the lowest pH (5.20) was observed in G_1 genotype (Table 3). The percent of titratable acidity (TA) of sugar apple varied significantly among the genotypes. It was found that the fruits of G_2 had the maximum percent of titratable acidity (0.25%) followed by G_1 (0.24%), while it was the lowest (0.19%) in G_3 (Table 4).

The maximum amount of ascorbic acid (36.28 mg 100 g^{-1}) was observed in G_3 followed by G_2 (33.65 mg 100g^{-1}) and the minimum value (29.40 mg 100 g^{-1}) occurred in G_1 (Table 4).

Total soluble solids (TSS) is an indicator of fruit sweetness. The highest total soluble solids (25.50 ºBrix) was obtained in G_2, followed by G_1 (24.48 ºBrix), and the lowest ascorbic acid occurred in G_3 (23.86 ºBrix).

The maximum total sugar and reducing sugar content (20.06%, 15.36%) were estimated in G_2, whereas the minimum total sugar and non-reducing sugar (18.63%, 3.87%, respectively) appeared in G_3 (Table 4).

Mineral contents of sugar apple

Mineral contents of sugar apple varied significantly among the genotypes. Calcium (Ca) and magnesium (Mg) contents were the highest in G_2 (359.60 and 326.95 mg 100 g-1 DW, respectively), followed by G_3 (316.45 and 287.08 mg 100 g^{-1} DW), and the lowest in G_1 (315.04 and 229.33 mg 100 g^{-1} DW, respectively). The highest levels of phosphorus (P) and iron (Fe) were found

in G_3 (117.63 and 6.21 mg 100 g^{-1} DW, respectively), while the lowest levels were found in G_1 (90.05 and 4.42 mg 100 g^{-1} DW). Also, G_3 contained the maximum sulfur (S) (542.09 mg 100 g^{-1} DW), followed by G_1 (490.56 mg 100 g^{-1} DW) and G_2, which contained the lowest amount of sulfur (404.16 mg 100 g^{-1} DW) (Table 5).

Table 4. Biochemical traits of three sugar apple genotypes.

Genotypes	Titratable acidity (%)	Ascorbic acid (mg 100 g^{-1})	TSS (ºBrix)	Total sugar (%)	Reducing sugar (%)	Non-reducing sugar (%)
G_1	0.24[a]	29.40[c]	24.81[a]	19.50[b]	14.14[c]	5.36[a]
G_2	0.25[a]	33.65[b]	25.50[b]	20.06[a]	15.36[a]	4.70[b]
G_3	0.19[b]	36.28[a]	23.86[c]	18.63[c]	14.76[b]	3.87[c]
LSD 0.05	0.01	0.34	0.03	0.10	0.03	0.10
LSD 0.01	0.03	0.51	0.12	0.16	0.05	0.14
Level of significance	**	**	**	**	**	**

Different letters in the column showing statistical significant difference at 1% probability.

Table 5. Mineral contents of three sugar apple genotypes.

Genotypes	Ca (mg 100 g^{-1} DW)	Mg (mg 100 g^{-1} DW)	P (mg 100 g^{-1} DW)	S (mg 100 g^{-1} DW)	Fe (mg 100 g^{-1} DW)
G_1	315.04[c]	229.33[c]	90.05[c]	490.56[b]	4.42[c]
G_2	359.60[a]	326.95[a]	96.09[b]	404.16[c]	5.48[b]
G_3	316.45[b]	287.08[b]	117.63[a]	542.09[a]	6.21[a]
LSD 0.05	0.34	0.12	0.50	0.02	0.11
LSD 0.01	0.51	0.18	0.76	0.04	0.17
Level of significance	**	**	**	**	**

Different letters in the column showing statistical significant difference at 1% probability.

Discussion

Sugar apple genotypes appeared to be different based on fruit shape, size, color of flesh, seed counts, biochemicals, and mineral contents. Fruit morphological variations are a prominent indicator of plant response to climate, environment, genetic components, geographic region, weather, soils, etc. The timing of fruiting and flowering is correlated with optimal climatic conditions for the survival of progeny in their habitat (Lestari and Sofiah, 2015). Sugar apple is typically conical in shape, but can occasionally be nearly spherical. Annona squamosa fruit color is usually greenish-yellow and dark pink (Thakur and Singh, 1967). All of the hybrids differed in terms of fruit shape (round, conical, and cordate), fruit color (yellowish-green, greyish-green, light green, and red), and interior color (creamy-white, light pink, and white), which is consistent with Girwani et al. (2011). When mature, the pulp is velvety, extremely sweet, and flavorful (Mysore et al., 2008). Variations in skin and tissue color result from genetic diversity. The fruit length and width showed a range of variation from 4.05 to 10.00 cm and 4.05 to 10.00 cm, respectively (Jnapika et al., 2019). The fruit weight is a genetically controlled trait that differed substantially between landraces (Kumar et al., 2018; Bhatnagar et al., 2012). In sugar apples, one of the reasons for weight loss was due to the rapid respiration in ripe conditions. The seeded content of mature fruits ranged from a minimum of 39.20% to a maximum of 63.60%, with a mean value of 53.29% (Sonali and Bakane, 2020). In this study, the highest seeded fruit pulp contents (76.59%) occurred in the G_3 genotype, which is nearly similar to the findings reported by Sonali and Bakane (2020).

Seed traits of three sugar apple genotypes varied significantly. The variations in seed traits of sugar

apple were also noticed by Yadav et al. (2017). They observed that the number of seeds, seed weight, seed length, and seed width of sugar apple were 18–63 g fruit^{-1}, 7.27–26.12 g, 9.40–14.90 mm, and 5.10–8.32 mm, respectively. The variations in seed traits might be due to genetic differences and the accumulation of gibberellin hormones. The minimum seed weight might be due to the accumulation of lesser photosynthates in the seeds or might be due to genetic variation or variations in fruit size (Handique, 2022). The superiority observed for fruits of different sugar apple genotypes regarding the traits might be attributed to the role played by the growing conditions which might have affected the final composition of fruits. The highest moisture content of G_1 may be attributable to the brief length and width of the seeds and their low dry matter content. Mean pH values ranged from 5.03 to 5.7, indicating the low acidity of sugar apple fruit (Moura et al., 2019). The titratable acidity of sugar apple genotypes ranged from 0.19 to 0.24%. This result is in agreement with the findings of Sumitra et al. (2022) and Pawar et al. (2010). They noticed the variation of TA in sugar apples ranging from 0.07 to 0.38%. The ascorbic acid contents of tested sugar apple genotypes ranged from 29.40 to 36.28 mg 100 g^{-1} fruit flesh. Almost similar results were also reported by Priyanka et al. (2019). They showed the value of ascorbic acid of sugar apple was 13.67 to 34.78 mg 100 g^{-1}.

The total soluble solids (TSS) content of sugar apples varied from 19.32 to 29 ºBrix (Pereira et al., 2010; Silva et al., 2007). TSS contents of different sugar apple genotypes in this study ranged from 23.86 to 25.50 ºBrix. TSS content can be influenced by several factors, such as plant genetics, chemical and organic fertilization, irrigation, and temperature (Junqueira and Junqueira, 2014). In the case of total sugar content (18.63 to 20.06%), reducing sugar (14.14 to 15.36%) and non-reducing sugar (3.87 to 5.36%) of sugar apple genotypes, similar results were also reported by (Kumar et al., 2018; Sumitra et al., 2022). The reasons for observed quantitative differences in total sugar, reducing sugar, and non-reducing sugar of sugar apple genotypes may be due to the diversity of genetic profile, environmental conditions, adaptation to local area, harvesting, and postharvest practices. The minerals composition of tested sugar apple genotypes varied significantly. These variations may vary due to the influence of genetics, climatic patterns, soil properties, and the interaction effect of soil and climate.

Conclusion

From the findings of this study, different sugar apple genotypes performed differently regarding the morphological, biochemical, and mineral contents of fruits in the three sugar apple genotypes. Most fruit traits were superior in G_3 and G_2 compared to G_1. In addition, the G_3 genotype has purple-colored fruit, which makes it highly accepted in the market. Therefore, the G_3 genotype is a promising genetic resource for future varietal improvement.

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Conflict of interest

The authors indicate no conflict of interest in this work.

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